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ABSTRACT
Olive harvesting with hand-held beaters is a repetitive work, tiring and time consuming (more than 4-5 hours/day). Operators work with vibrating tools in not natural body postures: they are therefore exposed to various risks, especially at the upper limbs. Unfortunately, also if in the agriculture sector the number of the declared upper limb disorders increased in the last years, hand-arm vibration and incongruent upper limb postures are not yet well perceived.
~~In this work, the hand-arm vibration exposure and the OCRA index were calculated for different operators which used different electric olive beaters~~. In this work, the hand-arm vibration exposure and the OCRA index were calculated for five operators which used three different electric olive beaters. In all the observed tests both the hand-arm vibration and the OCRA scores produced results over the admitted limits. *A(8)* ranged between 8.6 ms^{-2} and 25.4 ms^{-2}, far from the 5 ms^{-2} daily exposure limit values admitted by the European law (European Directive 2002/44). The OCRA checklist values ranged from a minimum value of 13.32 (red light level and light risk) for the left limb and a maximum of 34.41 (violet, high level and high risk) for the right limb.

Relevance to industry.
This paper describes the analysis of the combined risks to hand-arm vibration and to upper limb disorders ~~risks~~ in a typical agricultural harvesting task with a manual handled tool powered by electric engine. ~~Tests were carried out during the olive harvesting with some operators using different hand-held machines.~~ Tests were carried out during the olive harvesting with five operators using three different hand-held machines. Both vibration and OCRA ~~scores~~ parameters were acquired.
Results showed that in all the observed tests both the hand-arm vibration and the OCRA scores were over the admitted limits. Beaters ~~transmit~~ transmitted vibration to both the operators' hand-arm system, but operators did not declare to perceive vibration at the right upper limb (because it was ~~only~~ less affected by the vibration stimulus than the left one).
~~To acquire reliable values for the upper limb biomechanical risk detection without vibration measurements, it is possible to refer to the user guide of the machines or to existent databases (as also allowed by the European Directive 2002/44). The manufacturers willingness is therefore necessary to write the machine vibration information in the booklet and to let these information available for the vibration databases~~.
To acquire reliable values for the upper limb biomechanical risk detection it should be necessary to use measured vibration data in field, avoiding personal judgments. When it is not possible to measure the vibration level, the employer should use the machine instruction, where the manufacturer should have written the vibration total value to which the hand-arm system is

subjected, if it exceeds 2,5 m/s^2 (European Directive 2006/42). When this information is not available in the machine instruction, the employer may refers to other sources (European Directive 2002/44), as databases provided by government or institutional bodies, including vibration values obtained by research specialists and vibration consultants.

Key words: hand-arm vibration, OCRA index, hand-held olive ~~harvester~~ beater

1. Introduction

Manual olive harvesting is a tiring task, usually carried out with machines (beaters) powered by a little engine acting on the head mounted on a light pole and equipped with oscillating carbon fibre sticks. The operator inserts the beater sticks into the tree foliage and the olive pick-up is directly obtained by the impact of the sticks on olives or indirectly by the vibration transmitted to the willowy branches. The target is to harvest the highest number of fruits in the shortest time, without damaging ~~the fruits~~ them.

Whatever is the motor type (pneumatic, electric or internal combustion engine) or head characteristics (flap, hook, beater), ~~these machines have usually a weight varying in a range of 2-10~~ these machines have usually a mass varying in a range of 2-10 kilograms and the electrics are the lightest. The high number of beats per minute (until 1300) causes the fruit detachment from the branches. Some authors (Lavee et al., 1982; Deboli et al., 2014) showed that the average force to detach the olives is around 3 N, with a fruit mass of few grams (olives of ~~the~~ *Frantoio* cultivar have an average mass of 3.5 g) (Tsatsarelis et al., 1984)~~)~~: it is therefore necessary to use tools that produce high acceleration levels to remove the fruits.

Deboli et al. (2016) analysed the tip sticks acceleration of different models of electric beaters and they never found values lower than 600 ms^{-2} (not frequency weighted) with a machine mass around 2 kg and a pole length of about 2500 mm. The combination of the machine configuration (low mass, long pole) and the high sticks velocity (never lower than 6 ms^{-1}) therefore produces high vibration total values measured at the operator's hands position. In-field measurements yielded to data around 20 ms^{-2} (Manetto et al., 2012; Calvo et al. 2014; Deboli et al., 2016) with peaks higher than 40 ms^{-2} (Çakmak et al., 2011).

Many authors studied the relationship between hand arm vibration exposure and human response (Gemne, 1997; Lundborg et al., 1998; Bovenzi, 1998; Bovenzi et al., 2000) and they agreed to affirm that the prolonged use of hand-held vibrating power tools could lead to the hand-arm vibration (HAV~~S~~) syndrome, which can interest the nervous, muscle-skeletal and vascular peripheral structures of the upper limb. For these reasons, the European Directive 2002/44/EC provided to assess daily limits to the vibration exposures of the operators at the workplace, in order to guarantee their health and safety.

Unfortunately, with their high acceleration values, beaters do not achieve acceptable daily vibration values to avoid the operators' hand-arm vibration risk, unless these machines are used only few minutes during the day (very often less than 5-10 minutes/day to stay under the daily limits admitted by the European Directive).

Calvo et al. (2014) observed that the operators perform about 25 to 40 approaches per minute to the tree branches with the machine head, usually with the arms over the shoulders for almost all the harvesting time. The frequency of the task, the arm position above the shoulders, the exerted force (the beater must be continuously addressed into the tree foliage and must forcibly hits the branches or olives) and the duration of the work cycle (the daily harvesting time with the beater switched on is never lower than 4-5 hours) are factors which may expose the operator to further risks: the upper limb working musculoskeletal disorders (UL-WMSDs). UL-WMSDs include different work-related musculoskeletal disorders (WRMSDs) at neck, shoulder, elbow, hand and wrist, such as epicondylitis, hand-wrist tendon syndromes, carpal tunnel syndrome and continuous strain trauma (Grieco, 1998). Acknowledged risk factors for UL-WMSDs are the high strength, repetitiveness of actions, awkward body and arm postures, deficiency of resting periods (Bao et al., 2006a, 2006b).

In the Member States of the European Union, repetitive strain injuries at the upper limbs were observed in many countries since many years (OSHA, 2000). In 2014 Great Britain showed the highest prevalence rates of UL-WMSDs in manufacturing and construction (HSE, 2015), but also the agricultural sector was not negligible.

Lifting and carrying heavy loads, repetitive and prolonged stooping and forceful repetitive cutting (particularly during the manual harvesting, weeding and pruning) are common tasks in agriculture, especially in smaller farms, quite spread in Italy. In Italy WRMSDs significantly increased in agriculture in the period 2010-2014 and in particular, UL-WMSDs in 2014 represented the 64% of the declared WRMSDs pathologies (Table 1).

Table 1 WRMSDs types declared in agriculture in Italy (2010-2014).

	2010	2011	2012	2013	2014
Hand-arm vibration	81	76	37	38	52
Lumbar disc herniation	845	932	926	1,087	1,217
Upper limb biomechanical overload	1,221	1,732	1,718	2,176	2,289
Total	2,147	2,740	2,681	3,301	3,558

(Source: authors' elaboration from INAIL data)

A problem in upper limbs disorder detection in agriculture is linked to the variety of tasks entailing biomechanical overload in different work cycles (Occhipinti and Colombini, 2016).
American and Swedish studies found high percentages of dairy farmers complaining upper extremity injuries (Pratt et al., 1992; Stal, 2000). Crop harvesting also expose the operators to several risk factors to hands, wrists, elbows and shoulders (Meyers et al., 2000; Fulmer et al., 2002; Davis and Kotowski, 2007; Facci et al., 2012). Scapula-humeral periarthritis, epicondylitis and tendinitis of the hand-wrist were found common in the meat processing and in the preserved vegetable packing (Grieco, 1998). Riihimaki (1995) underlined that repetitive movement of hands and wrists in ~~repetitive~~ food packing tasks could lead to the hand-wrist tendon syndrome. Upper limb complaints were also common in the tomato growing industry (Palmer, 1996). Walker-Bone and Palmer (2002) detected a further risk factor for hand-wrist disorders in agriculture: hand vibration ~~from~~ by hand mechanics agricultural tools. It is moreover well known since the nineties that the manual works with the arms postured above the shoulders may produce significant levels of fatigue even when the strength demand is not high (Wiker et al., 1990). The discomfort increases with prolonged exposure times, for instance ~~for~~ when the operator ~~that~~ uses hand-held olive harvesters for 4-5 hours per day (Fig. 1).

Fig. 1. Example of operator's posture observed in field during the olive harvesting with the beater.

There are therefore all the conditions to analyse the operator's double exposure to hand-arm vibration and to the beater handling during the olive harvesting.
There are many significant contributions for the analysis and assessment of repetitive task for the upper limb and for the definition of useful criteria to establish a risk factor (Colombini, 1998), but the OCRA (OCcupational Repetitive Action) method is the reference technique used by ISO 11228-

3: 2007 to establish ergonomic recommendations for repetitive work tasks, involving the manual handling of low loads at high frequency. This methodology considers all the relevant risk factors; it is applicable to multitask jobs and provides criteria for forecasting the occurrence of UL-WMSD in exposed working populations (Colombini and Occhipinti, 2012).
In operations with repeated gestures, the accurate description of the main postures and incongruous movements is a prediction element of articular localization of muscles and tendons work-related pathologies (Colombini et al., 2011).
~~The OCRA method includes the OCRA index and the OCRA checklist.~~
~~The OCRA index allows an analytical risk assessment, proper to the workstation and work organization design. The OCRA checklist is a very suitable tool for risk mapping with information of the "weight" of repetitive work. The mapping allows to define proportions in which are present workstations in green band (risk absent), yellow (very slight risk or doubt), red or purple (slight risk, medium and high risk).~~
~~Compared to the OCRA index, the OCRA checklist uses a simplified procedure to analyze the risk of biomechanical overload of the upper limbs. This method can be used both in the estimation phase of a risk presence in a yard (mapping phase), and in the next phase of the risk management.~~
~~The OCRA checklist analyzes all the performed tasks of the operator during his work shift.~~
~~The procedure allows to know which tasks, for their structural and organizational characteristics, expose the operators to any, mild, medium or high biomechanical overload risk to the upper limbs.~~
In the olive grove cultivation, Proto and Zimbalatti (2015) showed that the fruit harvesting was a severe task for the upper limbs, corresponding to a probability of risk of a disease occurrence greater than 21%.
Until now the hand-arm vibration and the UL-WRMSDs exposures have been separately analysed and discussed by the above researchers, without focussing on the combined risk. For this reason, aim of this work was to analyse the olive harvesting tasks of some operators using different electric beaters, to evaluate their exposure both to the hand-arm vibration and to the biomechanical upper limb overload risks. The goal was not only to analyze the risks separately, but also to understand if they were adequately considered each other and to suggest attainable solutions to avoid possible mistakes in the risk evaluation.

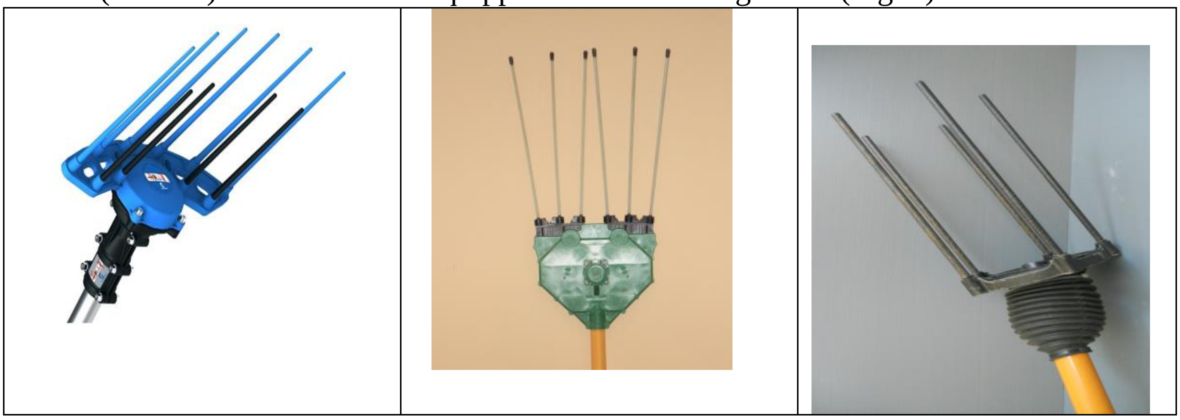
2. Materials and methods

2.1. Field site and cultivars

The olive grove, nine years old, is located in a hillside area at Moncalvo (Asti, Italy, 291 metres above the sea level, 45°03′02″ N and 8°15′45″ E) and it is a private property. *Leccino*, and *Pendolino* varieties are present. All the trees had a height from 220 to 400 cm.

2.2. Beaters

Three electric olive beaters, battery powered (12 V), and produced by two different manufacturers were tested (Table 2): their head was equipped with oscillating sticks (Fig. 2).



Beater #1 Beater #2 Beater #3

Fig. 2. The electric beaters.

Table 2 Beaters technical characteristics.

Technical data	#1	#2	#3
Beats per minute (bpm)	1200	1300	1086
Mass without power cord (g)	2800	2200	2200
Telescopic pole length (mm)	1800 - 2700	2200 - 3400	2500 - 4500
Sticks number	6 + 4	6	6
Sticks length (mm)	250 - 200	360	360
Stick diameter (mm)	6	6	10
Stick mass (g)	18	25.6	19.3
Stick material	Special composite	Special composite	Carbon fiber
Supply voltage (V)	12	12	12 - 24
Current consumption (work) (A)	7.5	4	5 - 4
Engine position	rear	front	rear

2.3. Operators

Only five operators were observed because for each of them each movement was analyzed with recorded videos. The recording time was very long and lasted all the working day. Moreover, three acceleration measurements were carried out for each operator using all the beaters, at both the front and the rear hand position, in the idling state and during the field work.

The five operators involved were between 27 and 64 years old, the mass was between 62 and 106 kg and the height range was 172 - 187 cm (Table 3). All of them were right-handed, they used all the beater models and were skilled in the olive harvesting with the beaters.

The five observed operators were between 27 and 64 years old, with a mass between 62 and 106 kg and the height range was 172 - 187 cm (Table 3). The low number of operators was due to the long time spent for deeply analysing each worker's movement for a correct calculation of the OCRA index. Each operator used all the beater models and all of them were skilled in the olive harvesting with the beaters.

Only the operator E had more than 6 years of experience in the beaters use. The olive beaters do not have handles and all the operators were right-handed: for this reason, the discussion of the vibration refers to the front hand position (left hand) and to the rear hand position (right hand).

Table 3 Operators' characteristics.

Operator	A	B	C	D	E
Age	55	27	38	64	40
Height (cm)	172	187	178	185	173
Mass (kg)	62	106	70	80	85

2.4. Hand-arm vibration measurement

2.4.1. Measurement chain and acceleration acquisition

Two tri-axial accelerometers (ICP - Integrate Current Preamplifier -, PCB SEN020 model, 1 mV/g sensitivity, 10 g mass) were fixed at the harvester poles using metallic clamps (EN ISO 20643: 2008/A1: 2012). The rear accelerometer was positioned near the power switch, close to the operator's right hand, while the front one was near the operator's left hand, accordingly to the anthropometric characteristics of each operator. The measurement chain was previously calibrated.
The NI (National Instruments) 9234 acquisition card was used to store the output signals from the accelerometers on a portable computer: the same data were then elaborated using the LabView software (National Instrument, 2012).
As required by the EN ISO 20643/A1 standard, accelerations were simultaneously measured along the three perpendicular axes (a_x, a_y, a_z, Fig. 3): the signals from the accelerometers were therefore

frequency weighted with the weighting curve *Wh* (ISO 5349-1 standard) and the frequency-weighted accelerations a_{hwx}, a_{hwy} and a_{hwz} were obtained.
As required by the EN ISO 20643: 2008/A1: 2012 standard, accelerations were simultaneously measured along the three perpendicular axes (a_x, a_y, a_z, Fig. 3). Each measurement was 3 minutes long. The signals from the accelerometers were therefore frequency weighted with the weighting curve W_h (ISO 5349-1: 2001 standard) and the frequency-weighted accelerations a_{hwx}, a_{hwy} and a_{hwz} were obtained.

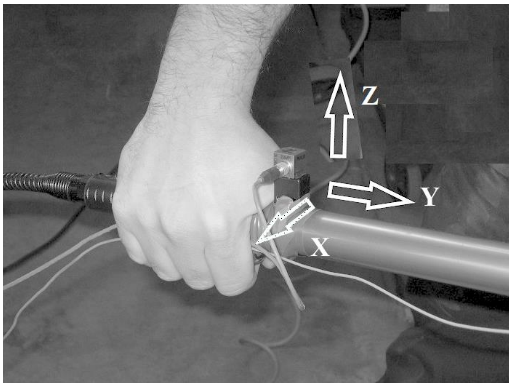


Fig. 3. Orthogonal axes positioning of the tri-axial accelerometer.

2.4.2. The vibration total value (a_{hv}) and the equivalent vibration total value ($a_{hv,eq}$) measurements

Three series of tests were carried out for each operator and beater, at both the front and the rear hand position (EN ISO 20643, 9.1), in the idling state (with the beaters switched on and hold by the operator without working) and during the field work.
Three series of tests were carried out for each operator and beater, at both the front and the rear hand position (EN ISO 20643: 2008, 9.1). Each acquisition in field was carried out distinguishing the initial beater ignition (the idling phase, that occurred when the operator was already near the three) from the harvest work (corresponding to the full load).
For each test, beater, operator and hand position (front and rear), the vibration total value (a_{hv}) was calculated using the frequency-weighted accelerations (Eq. (1)).

$$a_{hv} = \sqrt{a_{hwx}^2 + a_{hwy}^2 + a_{hwz}^2} \qquad (1)$$

The CEN/TR 15350:2013 was the guideline used to calculate the equivalent vibration total value $a_{hv,eq}$, as the time-averaged sum of the vibration total values a_{hvi} of the two beaters operating modes (idling and full load) during their associated exposure durations T_i (Eq. 2). The CEN/TR 15350: 2013 states that the fruit harvesters are usually used at the idling condition (ignition, displacement, rest) for 1/7 of their daily time and at the full load (work condition) for the remaining 6/7: these values were used for the equivalent vibration total value calculation. The sum of each exposure duration T_i within the entire work cycle (idling and full load) is the total exposure duration, namely the time T along the day when the operator's hand is gripping the pole with the beater switched on.
Moreover, also if the a_{hvi} were registered at both the front and the rear hand position, only the highest value (measured at the frond hand position, as explained in the result chapter) was used in the Eq. (2) to calculate the equivalent vibration total value (EN ISO 20643: 2008, 6.2).

$$a_{hv,eq} = \sqrt{\frac{1}{T}\sum_{i=1}^{2} a_{hvi}^2 T_i} \qquad (2)$$

2.4.3. The daily vibration exposure calculation

The daily vibration exposure (*A(8)*) of each operator was calculated as indicated by the European Directive 2002/44/EC ~~EU~~ (Eq. (3)).

$$A(8) = a_{hv,eq}\sqrt{\frac{T}{T_0}} \quad (3)$$

where:
$a_{hv,eq}$: equivalent vibration total value
T: total exposure duration (hours)
T_0: reference time (8 hours)
The daily vibration exposure is a subjective data and it is influenced by both the measured accelerations and the exposure times to the vibration source. There is any rule or technical report that indicates how long must be the exposure time when using the electric beaters: some authors observed a range between 4 and 5 hours/day (Manetto et al. 2012, Calvo et al. 2014). In this work the use of the beater in field, obtained by operators' interview, was 5 hours/day with the beater switched on.

2.5. Videos and interviews to detect the operators' behaviour
The behaviour and the movements of each operator were recorded using a camera (a PJ530 Handycam, Sony). A video was recorded for each operator and for each beater during the working day. ~~Fifteen recording were produced~~. Fifteen recording, each of them about 30 minutes long, were produced. Two days were spent for recording operators' movements and postures. The videos were then analysed and studied both to obtain the parameters for the calculation of the OCRA index and for better understanding the posture of each operator as well as the attitude to manage the beaters during the work. The analysis of the movies recorded in field permitted to detect the sequence and the timing of the tasks for each operator, other than the number of both the repeated movements and the critical postures.
The operators were moreover interviewed to gather information such as the necessary force (based on the Borg scale) to grip the beater during the harvesting, other than times and durations of each movement, according to the recommendations indicated in the OCRA method (Colombini and Occhipinti, 2006).

2.6. The OCRA method
The OCRA checklist method was used as described in the ISO 11228-3: 2007. The OCRA checklist analyzes all the performed tasks of the operator during his work shift and allows to know which tasks, for their structural and organizational characteristics, expose the operators to any, mild, medium or high biomechanical overload risk to the upper limbs.
~~The OCRA checklist is a method simpler than the OCRA index and analyzes the same risk factors for each upper limb. Operator's exposure level is classified in a five-zone band: green, yellow, light red, medium red and violet (Table 4).~~
The method consist of four steps: job and tasks description, hazard identification and risk evaluation, overall risk classification and remedial actions.
The job description and the task analysis include the workplace (in this case the area below the canopy of the olive trees, where the operators worked with the beaters) the involved operators (with their physical characteristics, as described in Table ~~2~~3) and the performed operations (in this case the olive harvesting).
The OCRA checklist hazard identification was then applied. It is composed by five sections: four of them refer to the major risk factors (lack of recovery periods, task frequency, grip strength, awkward postures), the last concerns additional factors (vibration, cold temperatures, precision work, setbacks, ..).
Video shots (collected for each operator) were fundamental to analyze the characteristic, the number and the duration of each performed task and to verify the awkward postures. The awkward

postures were determined analyzing, for the right side, both the duration of the flexion-extension movement of the elbow, and for the left side the raising of the arm above the shoulder.
The analysis of each movie, in fact, allows the evaluation of the risk posture affecting the upper limbs through the following steps:

- the description of the upper limb postures and of their incongruous movements;
- the temporal incidence of the awkward postures over the total work cycle (1/3, 2/3, or 3/3 of the cycle time, which have different computational weights, as indicated by Colombini et al. (2011));
- the presence of identical movements of the upper limbs repeated for more of the 50% of the cycle, corresponding to the time necessary to complete a tree harvesting;
- the presence of static positions of the upper limbs for a period over the 50% of the working time or less than 15 seconds.

The Exposure Index (*EI*) was therefore calculated (Eq. (4)) to determine the risk factor for each upper limb of each operator (Colombini et al. 2011).

$$EI = (f + s + p + c) \cdot r \cdot nt \qquad (4)$$

where:
EI: exposure index (or OCRA score)
f: frequency of the technical actions
s: strength force
p: incongruous posture, in function of the time (range 0-24)
c: complementary risk (range 0-6)
r: recovery multiplier
nt: net cycle time

The number of technical actions per minute (the frequency *f*) was calculated as the upper limb movements holding the beaters in each detected posture.
The strength force *s* was calculated (by personal interview) using the Borg CR-10 scale which expresses the perceived exertion. In particular, the expression of an extremely lightweight minimal effort was indicated with a value of 0.5, while a perceived exertion as extremely strong assumed the maximum value of 10.
The postural risk assessment *p* (a score determined by the type of the incorrect positions observed in the cycle) was firstly analyzed observing how many incongruous postures and movements occurred separately for the joints of: shoulder blades, elbows, wrists and hands (observing both the grip type and the fingers movements). If the joint was operating incongruously, the observing time was counted and it was considered if it exceeded 1/3, 2/3 or 3/3 of the repetitive working time.
The complementary factor *c* was set to 4 for the left hand. ~~since hand-arm vibrating instruments were used for at least 1/3 of the net cycle time~~.
The recovery multiplier *r* was calculated as the number of hours without an adequate recovery (at least 8-10 consecutive minutes per hour).
The net repetitive time duration was obtained subtracting at the total daily working time the time for the physiological breaks, for the meals and for the non-repetitive jobs. To complete the estimation of the net repetitive time, operators' interviews were used to collect further information concerning the required time to reach the workplace, the number and the average length of the programmed pauses.
The net cycle time (*nt*) was then calculated as the net repetitive time divided by the tree numbers and therefore compared with the measured total cycle time.
Attention was moreover paid at the presence of stereo-movements or at the same maintained work gestures, regardless of whether they occurred in incongruous postures, repeated movements or static actions retained for more than 50% of the net cycle time.

All the described parameters contributed to the calculation of the OCRA checklist EI. As indicated by Colombini et al. (2011), there are five risk groups (Table 4): values up to 7.5 refer to an acceptable risk for the upper limbs whereas a high risk to develop UL-WRMSDs is detected if results exceed 212.5. In the same table, the corresponding estimate of expected percentage of diseases of the upper limbs is underlined. The calculated EI was compared with these classes.

Table 4 Classification criteria of OCRA checklist and corresponding forecast of expected prevalence of workers affected by UL-WMSDs (%).

OCRA Checklist score	Risk Classification	Bands	Prediction of pathological risks UL-WMSDs (%)
Less than 7.5	No risk	Green	Less than 5.3
7.6 to 11	Borderline	Yellow	5.3 to 8.4
11.1 to 14	Light	Light Red	8.5 to 10.7
14.1 to 22.5	Medium	Medium Red	10.8 to 21.5
More than 22.5	High	Violet	More than 21.5

2.7. Data processing

Vibration data were organized into spreadsheets, used for the HAV analysis. Concerning the OCRA index, the acquired data were processed using a free worksheet (ERGOepmMINIcheckOCRAmonotask-ITA 16-11-15, www.epmresearch.org) produced by the Reaserch Unit "Ergonomics of Posture and Movement". All the data were then processed using the IBM SPSS Statistics 23 software package. The ANOVA ($p<0.05$) procedure was used to test the empirical evidence of differences or similarities among the operators and the beaters, both for the vibration and OCRA analysis.

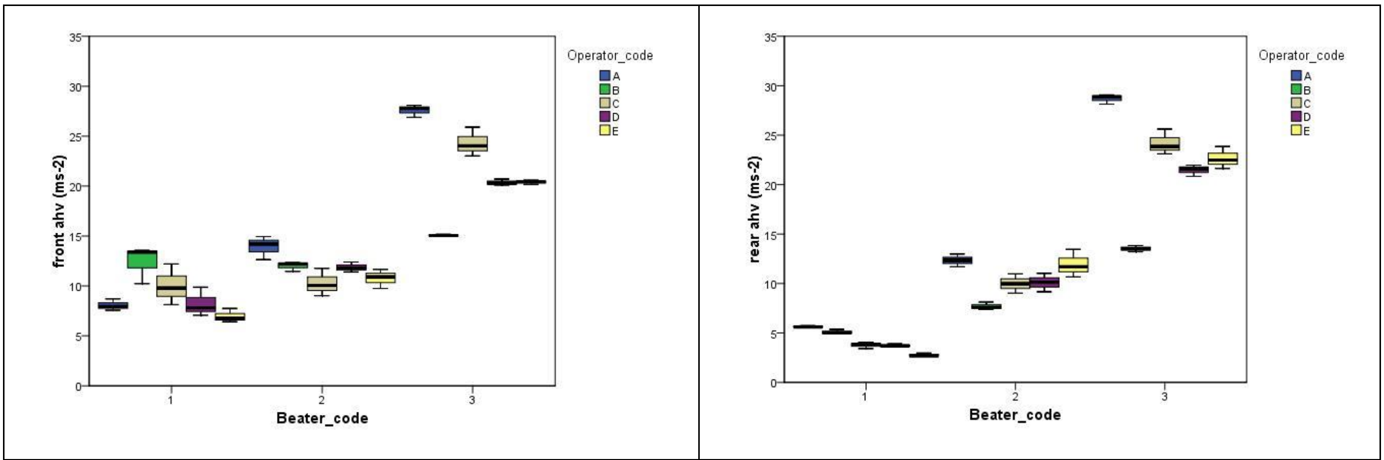
3. Results and discussion

3.1. HAV analysis

3.1.1. The vibration total values (a_{hv})

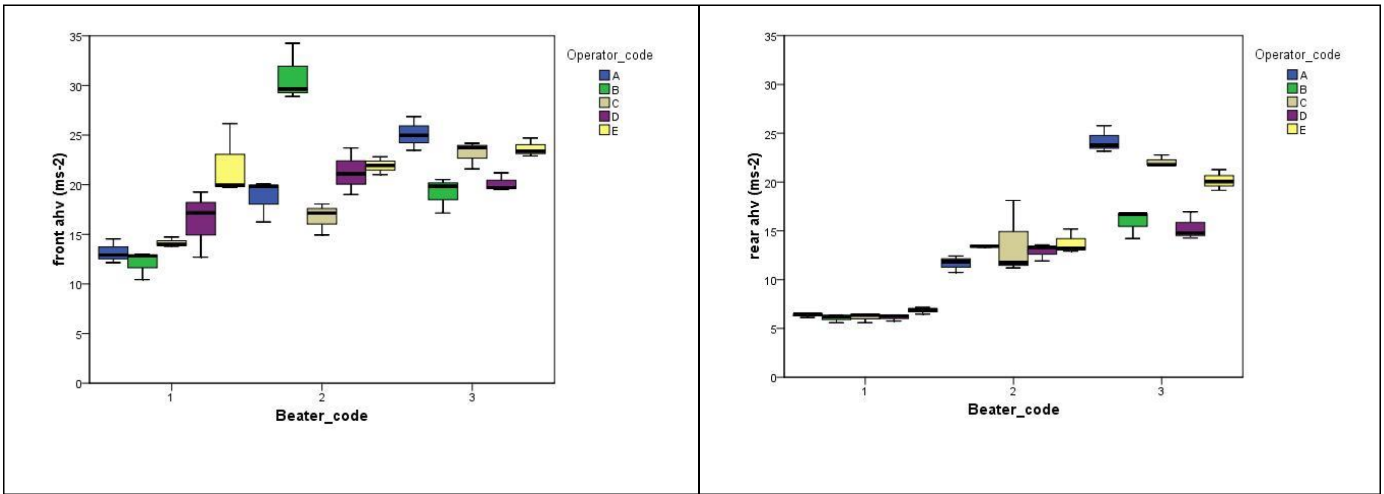
The ~~measured~~ acceleration, as vibration total values a_{hv} measured at the two hand positions, showed high variable data: from 3 to 29 ms^{-2} in the idling state and from 6 to 34 ms^{-2} in the full load condition (Fig. 4 and Fig.5, respectively). In the idling state, acceleration varied especially in function of the beater type (Fig. 4), at both the hand positions. In this condition, the beater #3 produced the highest acceleration values (about 21 ms^{-2} at the front hand position and 22 ms^{-2} at the rear), while only at the rear position the beater #1 produced the lowest and the uniform data (around 4 ms^{-2}). During the work (full load), at the front hand position were registered the highest values (from 10 to 34 ms^{-2} against the range 6-26 ms^{-2} obtained at the rear position). ~~The beater #1 (Fig. 5) showed lowest values during the work (from about 6 to 26 ms^{-2}), followed by the beater #2 (range 14-27 ms^{-2}) and the beater #3 (from about 10 to 34 ms^{-2}).~~ The beater #1 (Fig. 5) showed lowest values during the work (from about 6 to 26 ms^{-2}), followed by the beater #3 (range 14-27 ms^{-2}) and the beater #2 (from about 10 to 34 ms^{-2}).

A higher data variability was detected at the full load condition (especially at the front hand position): acceleration values were influenced by both the individual behaviour in the machine handling and by the sticks strikes against the tree branches (Fig. 5).



Front-idle | Rear-idle

Fig. 4. Vibration total values measured in the idling state at the front and rear hand positions.



Front-full load | Rear-full load

Fig. 5. Vibration total values measured during the olive harvesting (full load), at the front and rear hand positions.

~~As expected, the ANOVA procedure did never detect differences among the operators, while beaters where the elements which distinguished the acceleration measured and therefore they were differently grouped by the Tukey post-hoc test (Table 5). It is interesting to notice that the vibration total values are statistically different per beater type at the rear position.~~
As expected, the ANOVA procedure did never detect differences of the vibration total values among the operators at both the front and the rear hand position, while beaters where the elements which differentiated all the measured acceleration (Table 5).

Table 5. ANOVA of the vibration total values per operator and per beater in the different conditions (idling and full load) at the front and rear hand position

	Operator		Beater	
	F	Sig.	F	Sig.
front idle	0.552	0.698	70.856	0.000
front full load	1.050	0.394	12.187	0.000
rear idle	0.782	0.544	118.282	0.000
rear full load	0.381	0.821	114.148	0.000

Concerning the beaters, the vibration total values of the beaters #1 and #2 belonged at the same subset at the front hand position in the idling state using the Tukey post-hoc test, while at the same hand position the acceleration of the beater #2 and #3 were in the same subset in the full load condition (Table 6). On the other hand, the Tukey post-hoc test did not reveal any common subset for the vibration total values of the operators.

Table 6. Post-hoc Tukey test of the vibration total values of the beaters

Beater code	Front Idle (ms^{-2})		Front Full load (ms^{-2})		Rear Idle (ms^{-2})			Rear Full load (ms^{-2})		
1	9.14a		15.55a		4.20a			6.30a		
2	11.76a			21.91b		10.41b			13.09b	
3		21.55b		22.25b			22.10c			19.54c
Sig~~n~~.	.055	1.000	1.000	.973	1.000	1.000	1.000	1.000	1.000	1.000

3.1.2. The equivalent vibration total values ($a_{hv,eq}$)

For the calculus of the equivalent vibration total value $a_{hv,eq}$, only the highest vibration total values (corresponding to the front hand position) were used, as described in 2.4~~.2~~. The equivalent vibration total values were highly variable (Fig. 6) and heavily influenced by the beater type (except in the case of the operator E, who always reported values around 20 ms^{-2}).

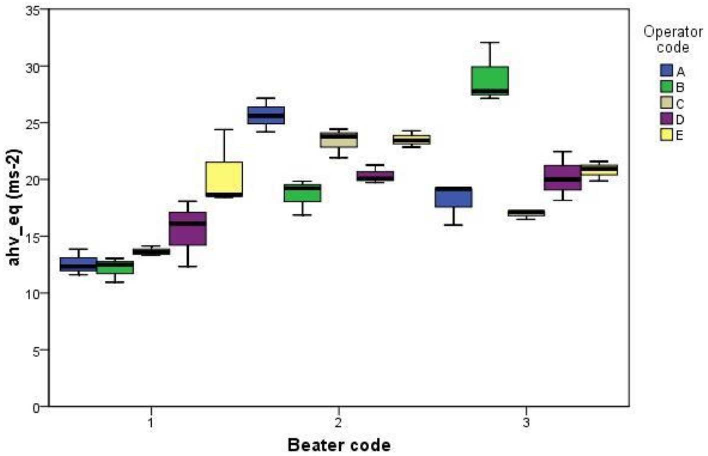
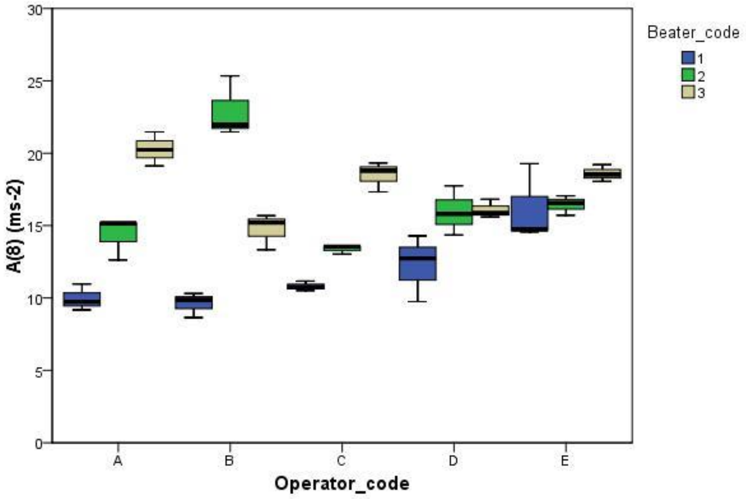


Fig. 6. Equivalent vibration total values ($a_{hv,eq}$) of the examined beaters, grouped ~~by~~ per operator.

3.1.3. The daily vibration exposures *A(8)*

Because of the high data variability among the beaters, the daily vibration exposure *A(8)* of each operator was calculated distinguishing the type of used beater and considering that all the operators worked with the machines switched on for 5 hours per day. Fig. 7 shows high exposure values, far from the 5 ms^{-2} daily exposure limit values admitted by the European law (European Directive 2002/44/EC). *A(8)* ranges between 8.6 ms^{-2} (best case reached by the operator B using the beater #1) and 25.4 ms^{-2} (operator B using the beater #2).
The ANOVA procedure confirmed that the daily vibration exposure values are significantly different by beater type, but with a very low significance, to enhance also the influence of ~~conditioning among~~ the operators ~~that use~~ when using the same beater.



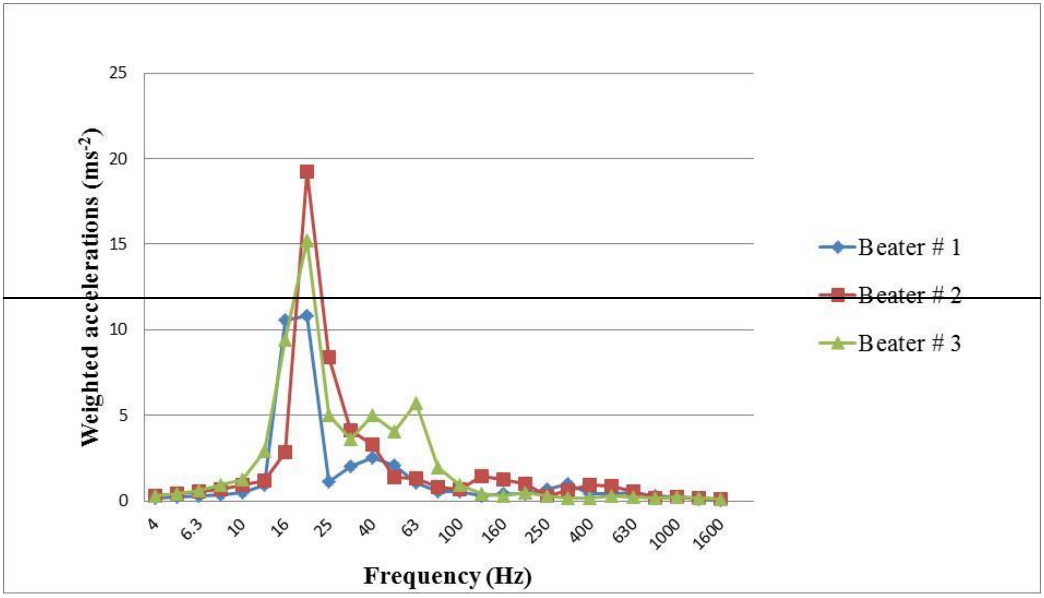
~~Fig. 7. Daily vibration exposure *A(8)*.~~

Fig. 7. Daily vibration exposure *A(8)* per operator, grouped per beater type.

To be coherent with the European Directive 2002/44/EC, in the best case the beater #1 should not be used more than 1h and 40 minutes by the operator B, whereas the same operator should not use the beater #2 for more than 11 minutes. In any case, the five operators should never use the beaters for the declared 5 hours of work, as also observed by other authors (Manetto et al., 2012; Calvo et al. 2014; Deboli et al., 2016). The movies moreover revealed another aspect: each operators had a different behaviour during the olive harvesting. Operators' gestures were different from each other and while some operators directed the beater head into the canopy losing the handgrip force, others continued to strictly grip the beater ~~handle~~ pole ~~also~~ when the sticks were into the foliage. This fact~~s~~ not only justify different vibration exposures as observed also by other authors (Vergara et al., 2008; Pascuzzi et al., 2009; Costa et al., 2013), but also different hand-arm movements and different awkward postures of the upper limb, that the OCRA index may reveal.

3.2. Frequency analysis

In Fig. 8 (left) there are the front position average weighted signals W_h at the different frequencies of the three beaters during the field work of the five operators.
The vibration level of the ~~tree~~ three beaters is centred in the 20 Hz one-third octave band, corresponding to the machines fundamental frequency. At this frequency, the measured weighted accelerations range from 11 to 18 ms^{-2} depending on the beater types. After this frequency, the second and third harmonics for beater #3 are present at 40 and 63 Hz, with an amplitude reduced by ISO 5349-1: 2001 weighting factor.



~~Fig. 8. Averages of the weighted (W_h) accelerations at the front (left) hand for all the operators.~~

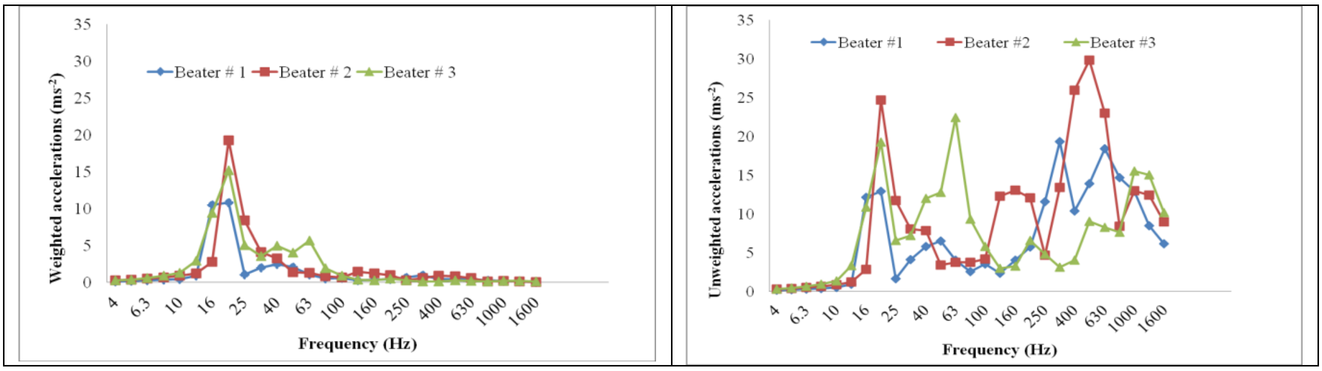


Fig. 8. Averages of the weighted Wh (left) and unweighted (right) accelerations at the left hand of all the operators

Many authors (Kihlberg et al., 1995; Thomas and Beauchamp, 1998; Dong et al., 2007; Dong et al., 2012) reported that the major wrist-forearm resonance is usually in the range between 16 and 40 Hz. Also Welcome et al. (2015) observed that the resonance vibration on the forearm is primarily in the 16-30 Hz range, with a peak amplitude of approximately 1.5 times the input vibration amplitude.

The operator's arms subjected to these frequencies, together with the high measured acceleration values, can undergo to arthralgias of the wrist and elbow joints, muscle pain and decreased muscular force (Bovenzi, 1998).

While in Fig. 8 (left) there is the graph obtained using the ISO 5349-1: 2001 (W_h) filters to the acceleration signals, in Fig. 8 (right) there is the graph of the same original unweighted signals, using a band limiting filter (ISO /TS 15694: 2004). Some authors (Bovenzi, 2012; Pitts et al., 2012), in fact, studied as the possibility of finger disorders produced by high frequency vibration were underrated when using the W_h filters only.

If we apply also the ISO /TS 15694: 2004 filters to the acquired signals, it is possible to see how the vibration energy is present also at higher frequencies, with peaks at 160, 400 and 630 Hz (Fig. 8, right). Some differences are evident between the weighted and the unweighted acceleration values in the three studied beaters (Figs. 8 left and right): in fact, their vibration total values differ of a factor of two, three, or more.

3.3. The OCRA index

All the interviewed operators agreed that the total working day was about ten hours, including the travel, the interruptions (for physiological reasons) and the meal (about 30 minutes). The average net duration of the turn was ~~therefore~~ 8 hours and the number of hours of repetitive work with the beaters without adequate recovery was 5 hours.
All the operators were right-handed: it was therefore recognized that the right upper limb was most affected, whereas the left arm was simply used to direct the beater into the foliage.
The observed frequency of the technical actions on the right side was between 4.50 and 9.00, with an average of 5.22 and a standard deviation of 1.37 (Table ~~6~~7). The force value was declared by all the operators as "moderate" corresponding to a value of 3 in the Borg scale: the force component was therefore assumed equal to 0 for the left hand and 1 to the right, because the time of the grip force was less than 1/3 of the work cycle.
The temporal incidence of the flexion-extension movement of the elbow to the right side had an average score of 3.49 with a standard deviation of 0.63 and a maximum of 4 (Table ~~6~~7). The resultant determined by the raising of the arm above the shoulder for the left side showed an average of 3.96 with a standard deviation of 2.02 and maximum value equal to 6 (Table ~~6~~7). For the right side, the aggravating circumstance of stereotipy condition was added, because the movies showed an extreme repetition of pushing the beater into the tree foliage. Additional factors concerned the use of vibrating tools. All operators unexpectedly advised vibration only at the left hand-arm system, while they did not perceived vibrational trouble at the right.

Table ~~6~~7 Sub indicators and OCRA scores for all the observed operators and the used beaters.

	Left				Right			
	Mean	St.dev.	Min	Max	Mean	St.dev.	Min	Max
Recovery	5.00	0.00	5.00	5.00	5.00	0.00	5.00	5.00
Frequency	0.00	0.00	0.00	0.00	5.22	1.37	4.50	9.00
Force	0.00	0.00	0.00	0.00	1.00	0.00	1.00	1.00
Posture (shoulder)	3.96	2.02	2.00	6.00	1.00	0.00	1.00	1.00
Posture (elbow)	0.00	0.00	0.00	0.00	3.49	0.63	2.00	4.00
Stereotipy	1.50	0.00	1.50	1.50	1.50	0.00	1.50	1.50
Additional factor	4.00	0.00	4.00	4.00	0.00	0.00	0.00	0.00
Checklist OCRA (EI)	**17.66**	**4.49**	**13.32**	**22.20**	**24.89**	**3.86**	**19.98**	**34.41**

~~The OCRA checklist values ranged from a minimum value of 13.32 (red light level and light risk range) for the left limb and a maximum of 34.41 (violet, high level and high risk) for the right limb (Fig. 9). The right side was the most affected with an average value of 24.89 (high risk level, standard deviation 3.86), while the left side average was 17.66 (medium risk level, standard deviation 4.49).~~
~~In Fig. 9 the box-wisker plots of the OCRA checklist per operator and per beater type underline the high values variability, especially at the left limb and for operators A and D. It is here interesting to notice how this variability does not affect the operator E, the same who showed different values also in the vibration analysis. At the right upper limb the OCRA checklist is always around 25 (higher than 22.5, the limit value of the high risk, Table 4), with peaks over 30.~~

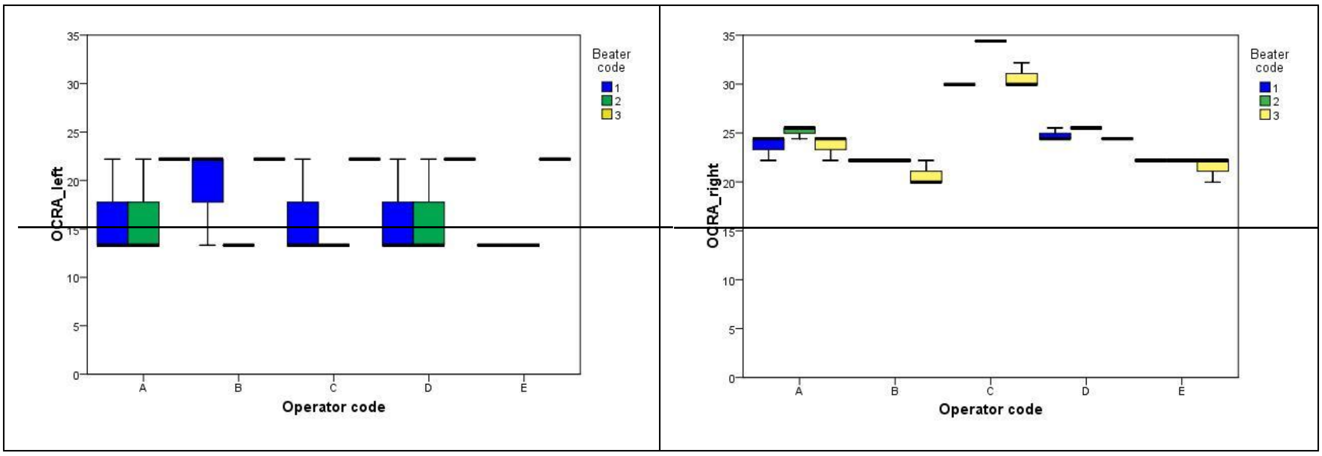


Fig. 9. OCRA checklist scores.

The beater influenced the OCRA values, both for the left and the right upper limbs (p-value <0.001). The operator influenced the results (p-value <0.001) only at the right side, while no significance was revealed at the left side. The repetition did not show statistical significance at both the sides, demonstrating the validity of the repeatability of the sampling methodology.
The post-hoc test showed three operator groups for the right limb (A with D, B with E, and C alone, Table 7) and two beater groups (1 with 3 and 2 alone, Table 8).

Table 7 Post-hoc Tukey test of the checklist OCRA scores per operator (subsets: α=0.05).

	Ocra score	
Operator	Left	Right
A	18.25 a	24.17 a
B	18.25 a	21.71 c
C	17.26 a	31.70 b
D	18.25 a	24.91 a
E	16.28 a	21.95 c
Sign.	0.606	<0.001

Table 8 Post-hoc Tukey test of the checklist OCRA scores per beater (subsets: α=0.05).

Beater	Left	Right
1	16.28 b	24.57 b
2	22.20 a	22.20 a
3	14.50 b	24.20 b
Sign.	<0.001	<0.001

The values obtained from the OCRA checklist showed, overall, a medium-high risk of skeletal muscle disease occurrence with a range of values between 13.32 (light risk) and 34.31 (high risk) (Fig. 9).
The OCRA checklist values ranged from a minimum value of 13.32 for the left limb (red light level and light risk range) to a maximum of 34.41 for the right limb (violet, high level and high risk), showing overall a medium-high risk of skeletal muscle disease occurrence (Table 78 and Table 89).
The right limb was the most affected with an average value of 24.89 (high-risk level, standard deviation 3.86), while the left limb average was 17.66 (medium risk level, standard deviation 4.49, Table 78).
Table 78 underlines the high values variability, especially at the left limb. The less affected at both the arms was the operator E, the same who showed different values also in the vibration analysis. At

the right upper limb the OCRA checklist is almost around 25 (higher than 21.5, the limit value of the high risk, Table 4), with peaks over 30.

Table ~~7~~8 OCRA scores per operator ~~and post-hoc Tukey test~~.

	Operator	Average	St.dev.	St.error	Min	Max
OCRA_left	A	18.25 ~~a~~	4.68	1.56	13.32	22.20
	B	18.25 ~~a~~	4.68	1.56	13.32	22.20
	C	17.27 ~~a~~	4.68	1.56	13.32	22.20
	D	18.25 ~~a~~	4.68	1.56	13.32	22.20
	E	16.28 ~~a~~	4.44	1.48	13.32	22.20
	Total	17.66 ~~a~~	4.49	0.67	13.32	22.20
OCRA_right	A	24.17 ~~b~~	1.21	0.40	22.20	25.53
	B	21.71 ~~a~~	0.98	0.33	19.98	22.20
	C	31.70 ~~c~~	2.16	0.72	29.97	34.41
	D	24.91 ~~b~~	0.59	0.20	24.42	25.53
	E	21.95 ~~a~~	0.74	0.25	19.98	22.20
	Total	24.89	3.86	0.57	19.98	34.41

Note: St.dev.: standard deviation; St.error: standard error

Table ~~8~~9 OCRA scores per beater ~~and post-hoc Tukey test~~.

	Beater	Average	St.dev.	St.error	Min	Max
OCRA left	1	16.28 ~~a~~	4.33	1.12	13.32	22.20
	2	14.50 ~~a~~	3.12	0.81	13.32	22.20
	3	22.2 ~~b~~	0.00	0.00	22.20	22.20
OCRA right	1	24.56 ~~a~~	3.02	0.78	22.20	29.97
	2	25.9 ~~a~~	4.65	1.20	22.20	34.41
	3	24.19 ~~a~~	3.78	0.98	19.98	32.19

Note: St.dev.: standard deviation; St.error: standard error

The beater influenced the OCRA values at the left upper limbs (p-value <0.001). The operator influenced the results (p-value <0.001) only at the right side, while any differences were revealed at the left side.
~~The post-hoc tests showed three operator groups for the right limb (A with D, B with E, and C alone, Table 7~~8~~) and two beater groups (1 with 2 and 3 alone, Table 8~~9~~) for the left limb.~~ Concerning the operators, OCRA scores were similar for all the operators at the left limb, while at the right limb likeness existed for the operators A and D and for the operators B and E (Table 8). On the other hand, the average OCRA score of the beater #1 was alike to the beater #2 (Table 9) at the left limb, whereas the scores were similar among all the three beaters at the right limb.

The main weight of the calculated upper limb risk was the number of repeated gestures. The frequency of the flexion-extension of the elbow, the arm lifting above shoulder level and the lack of the recovery component (as confirmed by the operators' interviews) were also important weights. The recorded values were reduced of about 20% with the presence of a recovery time: some authors (Faucett et al., 2007; Fathallah, 2010) proved that programmed rest breaks in some agricultural activities might significantly reduce the symptoms of the musculoskeletal discomfort without affecting productivity.
~~Beaters transmit vibration to both the operators' hand-arm system, but operators did not declare this problem at the right upper limb (perhaps because it was only less affected by the vibration stimulus~~

~~than the left one). As a consequence, the vibration component was not added as further factor at the right limb in the OCRA score calculation, probably misrepresenting the real condition. The vibration measurement, in fact, revealed high vibration values also at the right hand-arm system, with values never lower than 5 ms^{-2} for the beater #1 and around 13-23 ms^{-2} for beaters #2 and #3. The perceived subjective sensation may therefore lead to an incorrect evaluation of the OCRA index~~. The OCRA method does not actually consider the real vibration data, but simply account the vibration as a complementary risk (section 2.6). In this study, moreover, the operators did not declare to perceive vibrating stimulus at the right upper limb, probably because they felt it less affected than the left limb, also if the vibration measurement at the right hand-arm system provided values never lower than 5 ms^{-2}. Therefore, the vibration component was not added as complementary risk at the right limb in the OCRA score calculation.

Coenen et al. (2014) proposed a detailed analysis for the hand-arm vibration exposure evaluation (whereas vibration intensity is unknown) based on the operator's descriptions of different levels of vibration perceived, to have a more precise answer on the vibration transmitted.

4. Conclusions

The olive harvesting with the beaters is a repetitive work, time consuming (more than 4-5 hours/day) and tiring. Operators are exposed to various risks, because they use high vibrating tools in not natural body postures. Especially upper limbs may be affected.

In this work, ~~different~~ five operators used ~~different~~ three electric beaters for olive harvesting. The results were always concordant: in all the observed tests, both the hand-arm vibration and the OCRA scores were over the admitted limits.

~~Olive beaters are quite new machines and ULMSD's appear only after some years of work: it is therefore important to correctly evaluate the risk a priori~~.

The vibration behavior of the olive beaters has been studied since few years and UL-WMSDs appear only after some years of work: it is therefore important to correctly evaluate the risk a priori.

The legislature ~~in these last years~~ nowadays owns tools to prevent the hand-arm vibration risk and the ~~ULMSD's~~ UL-WMSDs (for example the European Directive 2002/44/EC and the ISO 11228-3: 2007), but they are separately used. Moreover, also if in the agriculture sector the number of the declared upper limb disorders increased in the last years, workers do not perceive hand-arm vibration and incongruent upper limb postures risks.

Occupational health practitioners should therefore enhance the risk assessment of hand-arm related tasks with the available methods and instruments. ~~Also~~ Ergonomic interventions should also be implemented with the direct intervention of the workers and with a deeper knowledge of the risk. As observed also by Douwes and de Kraker (2014), further studies are necessary to better integrate the vibration risk in the ULMSD's evaluation, possibly completing the methodology for the upper limb disorders detection with reliable vibration data, not only obtained by subjective perceptions. ~~Since hand-arm vibration are difficult to measure, a possible solution (as also considered by the European Directive 2002/44) is to refer to the user guide of the machines or to existent databases (quite spread in the last years), where it is possible to obtain vibration values congruent with the used tools: in this way it is possible to refer to reliable values, avoiding possible incorrect personal judgments.~~ When it is not possible to measure the vibration values, a viable solution is to use the hand-arm vibration total values written in the user manual of the machines (European Directive 2006/42/EC). When neither this information is available, the European Directive 2002/44/EC allows referring to other sources, as databases provided by government or institutional bodies, or by research specialists and vibration consultants. The aim is to use reliable vibration data for the OCRA score calculation, as not only a complementary factor, but also using a scale of values in function of the measured or assessed vibration exposure.

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